Photoneutron Calibration for CDMSlite
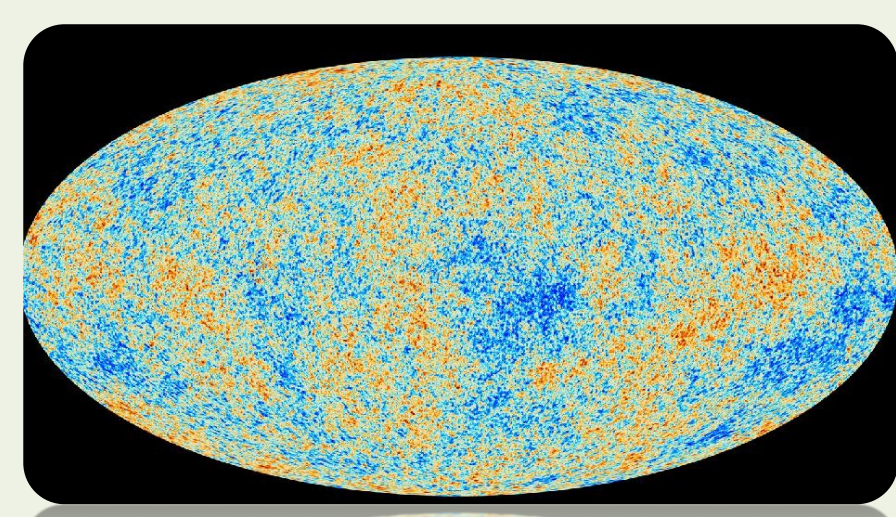
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Dark Matter

Dark matter constitutes 85% of matter in the universe, yet has only been observed gravitationally. Little is known about its nature, however we can measure its existence and learn about its distribution from a variety of sources, such as...
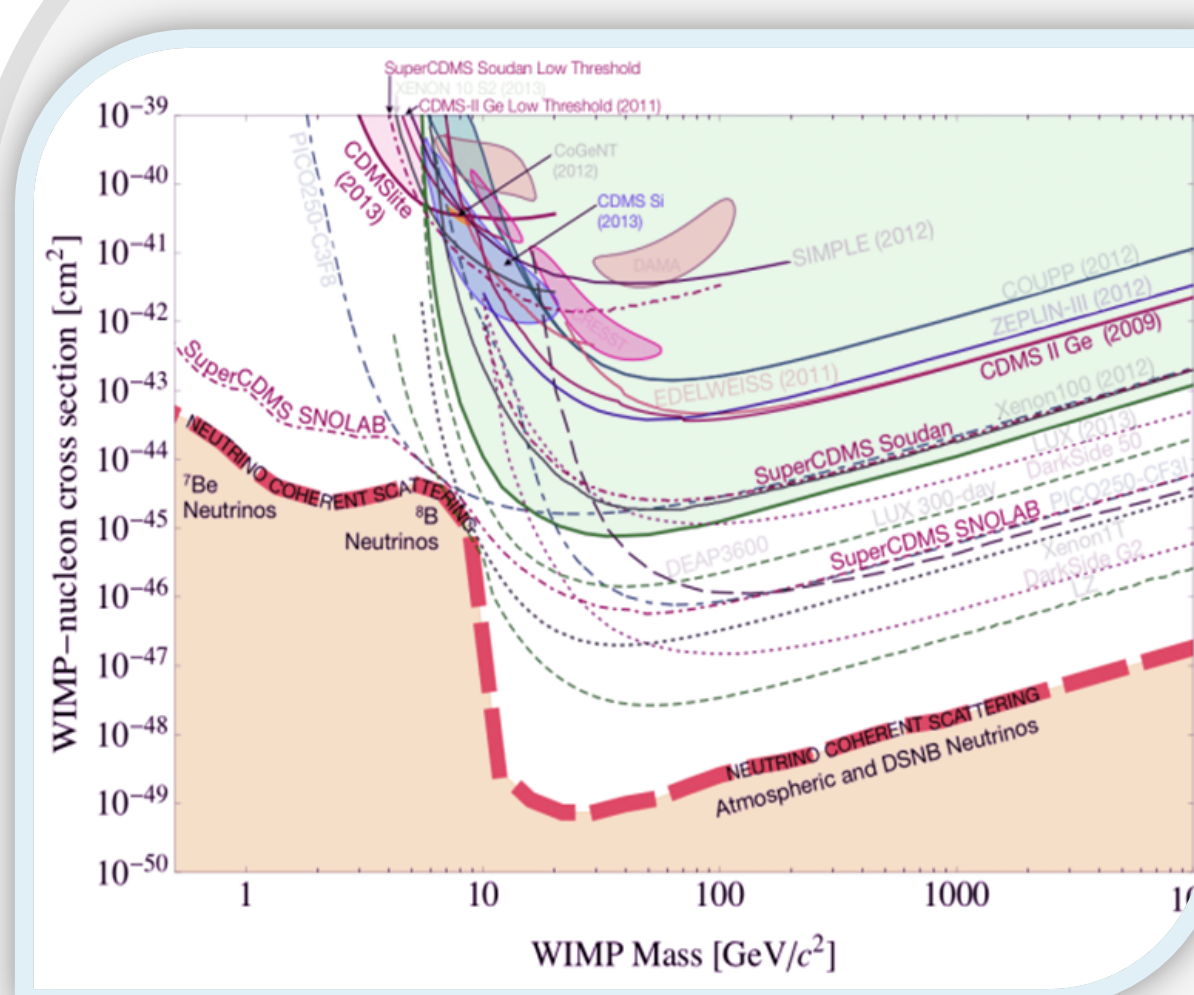
Galactic Rotation Curves	The Cosmic Microwave Background	Gravitational Lensing

...amongst others. There are a variety of theories for what dark matter might be, for example: sterile neutrinos, axions, and Weakly Interacting Massive Particles (WIMPS). However, until dark matter is observed directly, its identity remains unknown.

CDMSlite

The Super Cryogenic Dark Matter Search (SuperCDMS) uses germanium detectors to search for WIMPs, a potential dark matter candidate.

CDMSlite is a high-voltage (70V) extension of SuperCDMS that can probe lower mass ranges than have previously been observed with advanced detectors.

Figure: CDMSlite's WIMP mass (and cross-sectional) sensitivity range in relation to other past [solid] and future [dashed] detectors.

When WIMPs interact with the atoms in the Germanium detector, they are expected to produce nuclear recoils. This is different from the gamma background, which produces election recoils.

In conventional SuperCDMS, data is collected along both ionisation energy and phonon recoil energy channels. However CDMSlite sacrifices the latter for low-mass sensitivity. The energy of a nuclear recoil, therefore, must be deduced from only the ionisation energy and the 'quenching factor' – that is, how much of the total energy goes into the ionisation channel.

There is a theoretical calculation for the quenching factor by Lindhard, however there is strong experimental precedent suggesting this parameter often varies significantly from both the theoretical prediction, and even from detector to detector, making an accurate measurement of the quenching factor in CDMSlite incredibly important to interpreting any results.
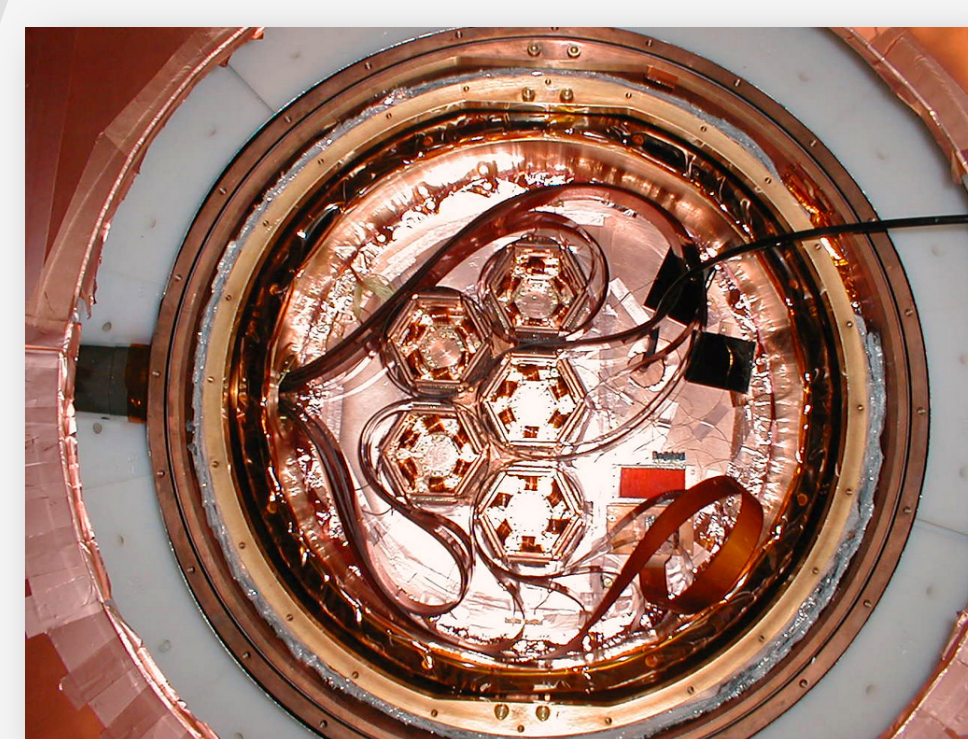
Photoneutron Calibration

A neutron source is ideal to calibrate CDMSlite, since neutrons produce a nuclear recoil signal in the detectors very similar to the signal expected from WIMPs.

However, cannot use a simple neutron source; the energy spectrum is smooth and it is difficult to calibrate without easily identifiable features. Instead, **photoneutron calibration** is better. Here, we use high energy gammas from a radioactive isotope (antimony ^{124}Sb or yttrium ^{88}Y in this case) to manually eject neutrons from a sample of beryllium. These neutrons have an energy well-defined by kinematics, but without the cost or difficulty of transporting the experiment to a monoenergetic neutron beam.

Once these neutrons reach our detector, the measured energy spectrum of the photoneutron source should have a clearly visible **hard shoulder**, characterised by a rapid drop in the recorded number of events at a predicted total phonon energy. For SbBe elastic scattering, this should occur at 1.3keVnr (nuclear recoil equivalent). Using Lindhard's calculation for the yield (0.177) of our germanium target, we calculate the total phonon energy we anticipate to measure for the hard shoulder:

Total phonon energy   Recoil energy   Luke phonon energy

$$p_{total} = p_{recoil} + Q(V/3.0)$$
$$= p_{recoil} (1 + \text{Yield } (V/3.0))$$
$$= 1.3 (1 + 0.177(70/3.0)) = \textbf{6.669keV}$$

Experimental Set-Up

| Source   Gamma Shield |
| Detector Block |
| Icebox Layers |
| 10cm Inner Poly |
| **22cm Lead** |
| **40cm Outer Poly** |

Cross section for neutron ejection extremely small. Expect 10^5 gamma events per single neutron event!
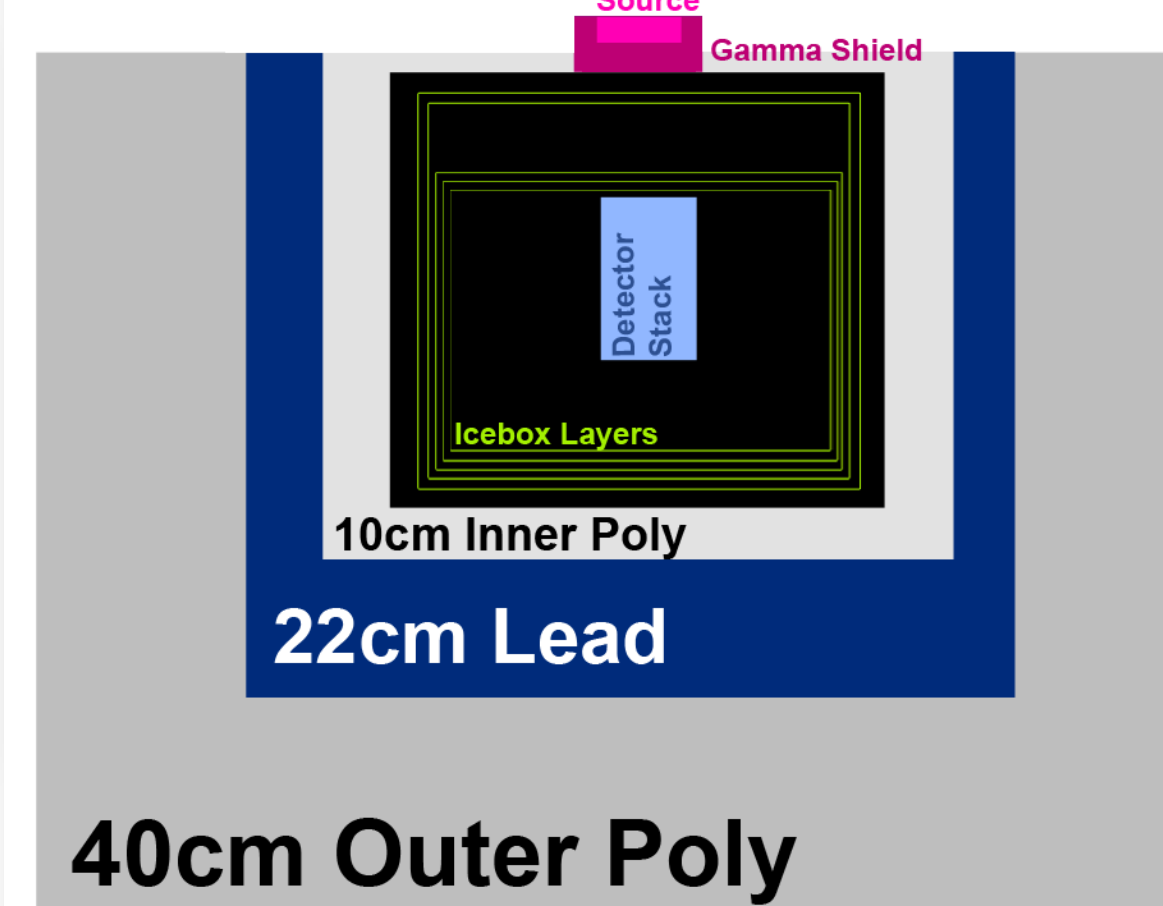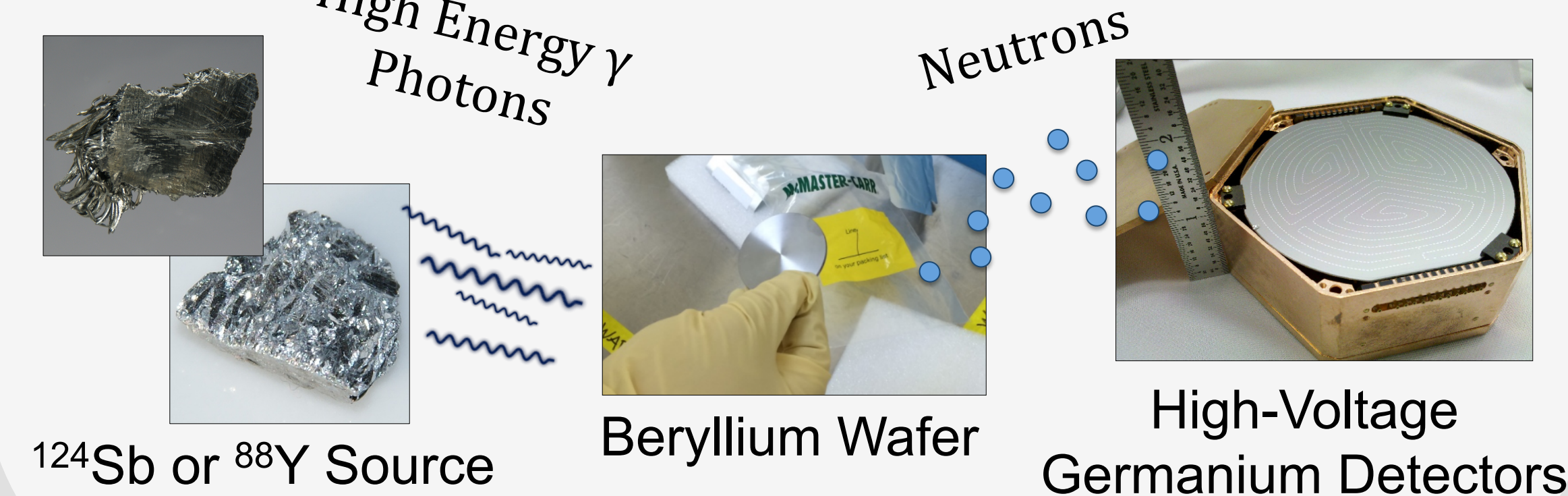
Substantial shielding is used to block out background gammas.

SuperCDMS can discriminate nuclear (from neutrons) and election (from gammas) recoils on an event-by-event basis from the ionisation to phonon energy ratio. However, since CDMSlite can only measure ionisation energy, we block out as many election recoils as possible with substantial lead and polyethylene shielding. We then measure the spectra with and without the neutrons (we turn the neutrons off by removing the Beryllium wafer) and use a subtraction of the two to ensure we are viewing only the neutron events.
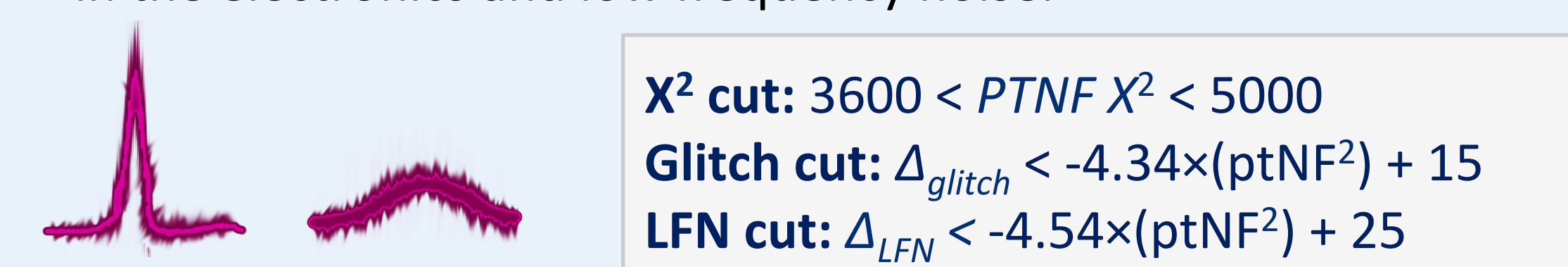
Data was taken for five weeks of SbBe and SbBlank modes. YBe and YBlank modes will follow soon.

Since source configuration was changed by hand, the length of SbBe and SbBlank runs may vary by a number of days. This is counteracted by normalising collected spectra by their cumulative livetime.

High Energy γ Photons   Neutrons

^{124}Sb or ^{88}Y Source   Beryllium Wafer   High-Voltage Germanium Detectors

Quality Cuts

❋ We want to observe well-shaped phonon events. (Sharp rise and slow fall.) X^2 cut fits events to phonon shape and rejects events that do not match, such as pile-up and saturation events.

❋ Analysis cuts remove other events that may pass the X^2 cut but have similar shapes – i.e. abnormal pulses caused by glitches in the electronics and low frequency noise.

X^2 cut: $3600 < PTNF\ X^2 < 5000$
Glitch cut: $\Delta_{glitch} < -4.34 \times (ptNF^2) + 15$
LFN cut: $\Delta_{LFN} < -4.54 \times (ptNF^2) + 25$

Glitches and LFN(above) compared to phonon(right).

❋ Need to flash the detectors regularly to ensure no charge build-up.

❋ Ensure the detector is operating at desired voltage (between -68V and -72V).
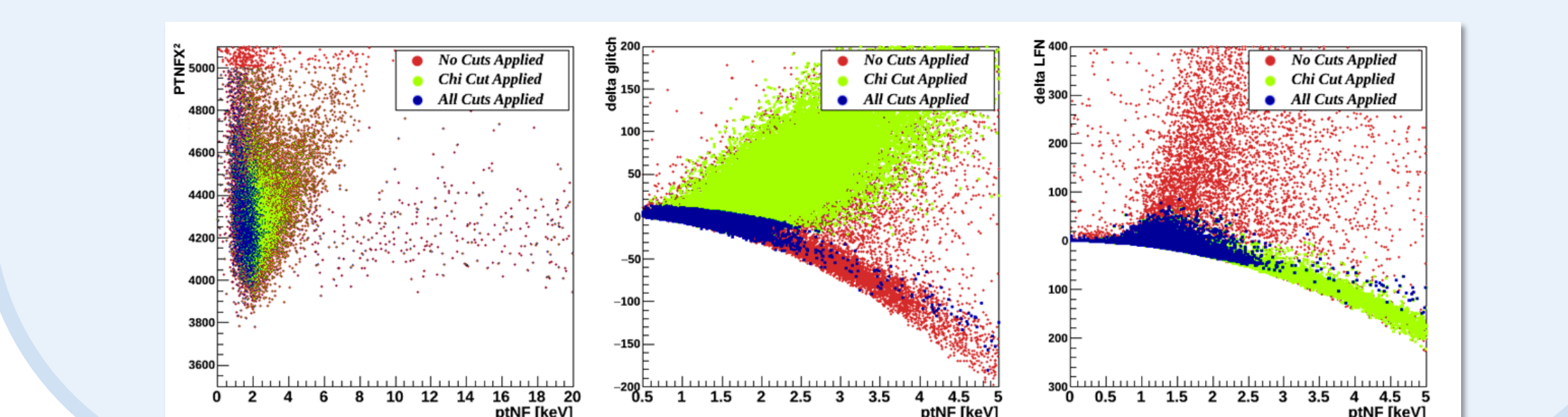
Miscalibration

Note that there is a miscalibration in the ptNF scale, due to analysis done at 4V which has not been corrected for. Also a small current drop (current leakage) means detector may be operating at a little less than 70V. The Lindhard calculation assumes both are correct and so will vary from our measured value. Work is being done to correct for both factors, though the former will have a more significant effect.

Systematic Checks

Source Decay
Our ^{124}Sb source has a half-life of 60.2 days. This corresponds to a decay constant of λ=0.0115 and means that over a 3-day turnaround period we expect to see a decline of 3.4% in the signal between SbBe and SbBlank modes within one week. This is a small difference, but should be in one's mind when comparing spectra.

Temperature Change
Between weeks 1 & 2, and weeks 3, 4 & 5, the detector experienced a drop in temperature of a few milli-kelvin. The spectra before and after this event was compared to see if it made a substantial difference to the results.
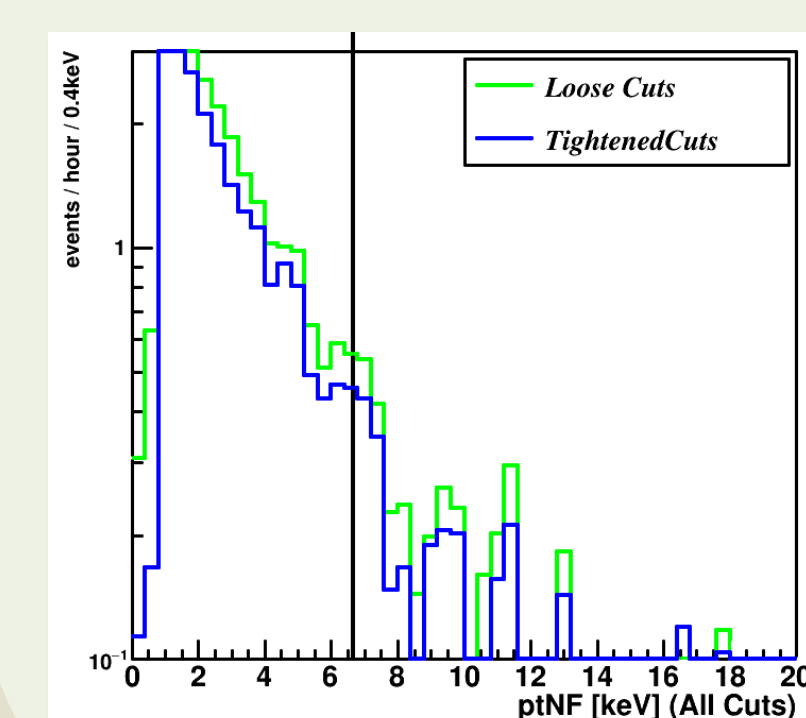
Tightening Analysis Cuts
It is important to keep cuts tight enough to remove bad events, but not so tight that they exclude good events. Cuts were tightened and the spectra before and after were compared.
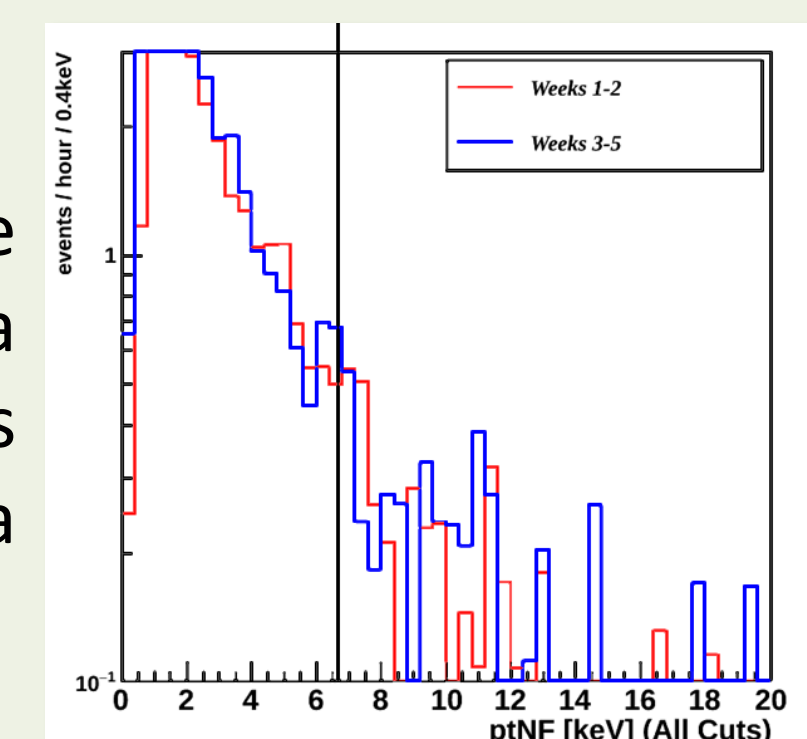
Resulting Spectra

We observe a clear excess in the neutron-on mode – indicative of our spectrum.

Comparing with the simulated spectrum and representing the theoretical value for the neutron hard shoulder in total phonon energy (6.669keV) as a black line, we see what may be the shoulder at around 8keV.
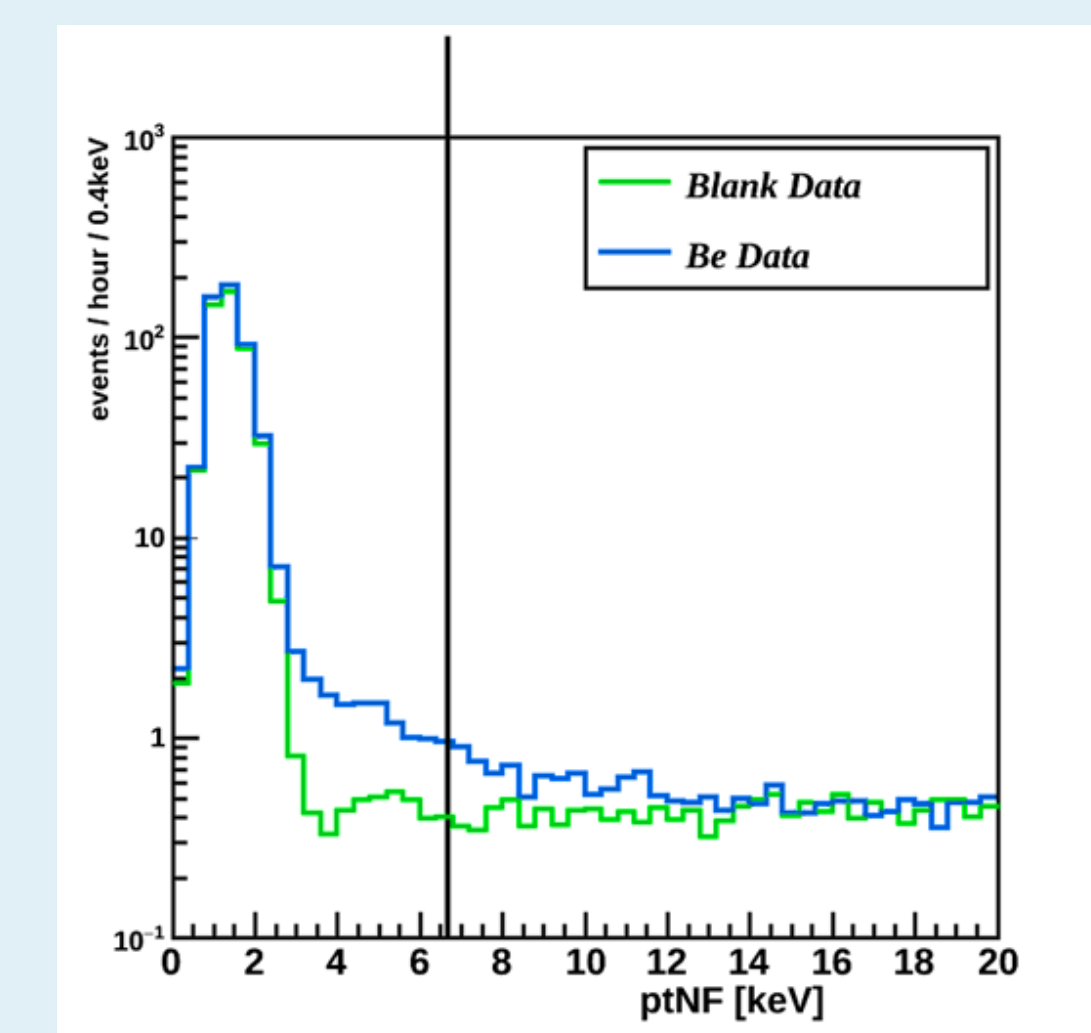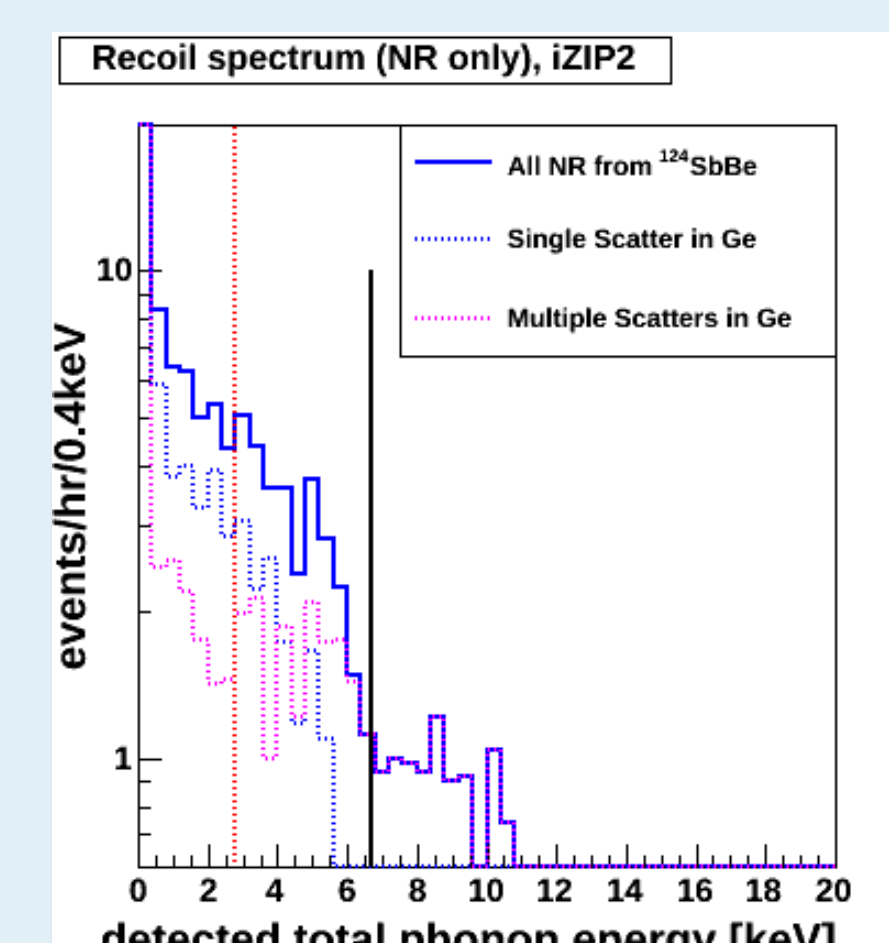
Further analysis, accounting for the miscalibration in the detector and comparing with the yttrium data should deduce the precise location of the hard shoulder and enable us to determine the quenching factor for CDMSlite.
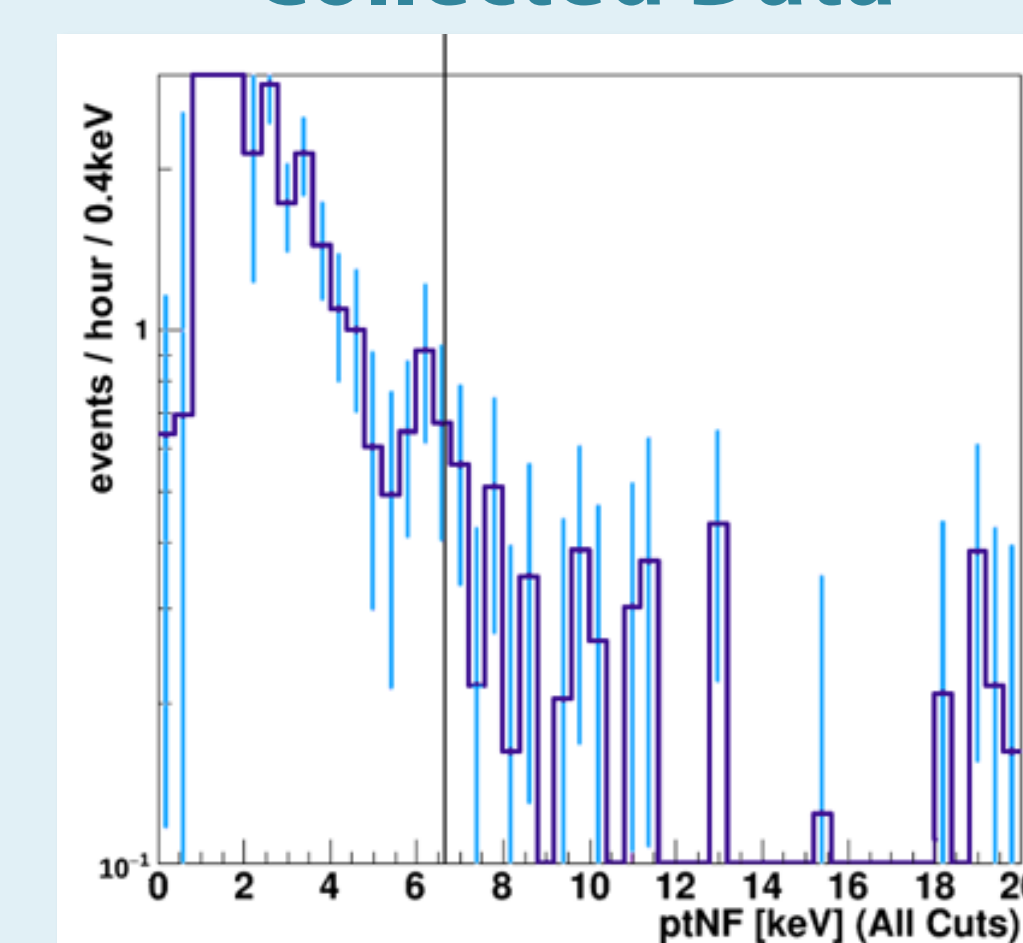
Collected Data   ### Simulation

Next Steps

❋ Correct for the source decay issue mentioned above. (Note that the three-day calculation above is a rough calculation and turnaround ranged from two to five days.) The spectra should be renormalized, taking this factor into account.

❋ Correct for miscalibration in detector. This can be done using the 10keV line that produces a strong signal in the detector and has a well defined total phonon energy. Fit a Gaussian to the measured signal and scale spectra accordingly relative to the actual value.

❋ Perform similar analysis on the yttrium data and clearly identify both hard shoulder and quenching factor.

❋ **The future**... SuperCDMS detectors will move from Soudan Underground Laboratory (2090 metres water equivalent) to SNOLAB (6060 metres water equivalent) in Canada, greatly improving sensitivity.